Wave Forecasts in Muddy Coastal Environments: Model Development and Real-Time Applications

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Award Numbers: N00014-03-1-0200
http://www.csi.lsu.edu

LONG-TERM GOALS

The objective of the work is to study wave evolution in cohesive sedimentary environments, toward the development of an effective, stochastic model for wave dissipation in these environments. The project will focus on prediction of surface wave evolution over relatively large spatial scales (scales of 100 wavelengths), intermediate depth to shallow water.

OBJECTIVES

The strong dissipative effects cohesive sedimentary environments have on waves are well known, but little understood. The commonly accepted long wave paradigm (only low frequency motion is affected due to strong interaction with the bottom) is contradicted by observations (Sheremet and Stone 2003) showing strong dissipation also in high frequency bands, where the direct wave-bottom interaction is weak. The goal of this project is to investigate short wave dissipation and develop a theoretical formulation for its mechanisms, and ise the resolts to develop a numerical formulation of dissipation terms, amenable to omplementation into existing stochastic spectral wave models (e.g. SWAN).

APPROACH

The observational component of this project is based on WAVCIS, a large ocean observing systems in operation at Louisiana State University. The system is operational and provides comprehensive real-time in-situ measurements. The project enhances WAVCIS' capabilities with sediment monitoring sensors.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2004**	2. REPORT TYPE	3. DATES COVERED **00-00-2004 to 00-00-2004**

4. TITLE AND SUBTITLE **Wave Forecasts in Muddy Coastal Environments:Model Development and Real-Time Applications**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Coastal Studies Institute, 331 Howe-Russell Geoscience Complex,,Louisiana State University,,Baton Rouge,,LA,70803**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The simulation component will consist of a fully detailed pilot model, integrated in a quasi-operational, nowcast mode, with the observation systems. The pilot model will implement theoretical approaches derived from the study, and will serve as a benchmark for skill assessing subsequent parameterizations of wave dissipation developed as modules for operational use. The resulting simulation/observation system (workbench) will help identify the dominant energy exchange mechanisms, their time/spatial scales, and ways to uncouple the surface wave and fluid mud/seabed motions. It will also maximize the exposure of development ideas to field data. The database of test cases will be established during the project.

WORK COMPLETED

The WAVCIS-based observational system has been monitoring continuously for the past year hydrodynamic and sedimentary processes on the Louisiana shelf. Data about the evolution of wave, current and sediment regimes on the shelf is archived and made available to the communiy through the web interface of the WAVCIS system. Suspended sediment concentration (SSC) is measured at a WAVCIS station near the 5-m isobath on the Atchafalaya shelf at 1, 2, and 3 m above the bottom (mab). Observations of SSC suggest that short-wave dissipation is strongly correlated with the formation of a near-bottom fluid mud layer in the waning stage of storms, due to sediment settling. The effect is remarkably clear in the case of stronger perturbations, such as Hurricane Claudette (Sheremet et al. 2004) , and recently, Hurricane Ivan. During these events, the estimated thickness of the fluid mud layer exceeded 1 m, with SSC values larger than 10 kg/m^3. The effect was first observed during cold front passages. Data collected this past year indicate that the thickness of the fluid mud layer in these events reaches typically 20-30 cm in thickness, with similar concentrations. These observations are significant, as they suggest that mechanisms other than direct, friction-like interaction are important in short-wave dissipation.

Several dissipation mechanisms were investigated. One difficulty is that many of these theories lead to a dispersion relation with a complex wavenumber; this requires extreme care in solution (Dalrymple et al. 1991) which would be inconvenient in the context of a numerical wave model. As a first attempt, we used the model of Ng (2000) to simulate the dissipation of wave energy by muds. This theory is a boundary layer asymptote of that of Dalrymple and Liu (1978), which assumes that the mud layer is a fluid of higher density and viscosity. Ng (2000) expressed the wavenumber as a perturbation expansion, allowing complex dissipative wavenumbers to be functions of the nondissipative, real-valued wavenumber and simplifying computation considerably. This mechanism was added to the model of Kaihatu and Kirby (1995), a nonlinear wave model for simulating the triad interactions redolent of waves in the nearshore and surf zones.

RESULTS

To understand the formation of the fluid-mud layer, mud dynamics were simulated using a one-dimensional numerical model proposed by Li and Parchure (1998) to simulate a non-equilibrium suspension profile. The focus of simulations was to describe the regime dominated by settling during the waning stage of the storm, when the gradual decrease in wave-induced turbulence shuts down the resuspension processes. The increase in concentration in the fluid mud layer supresses the turbulence further, accelerating the decay. The model used is based on a general mass-conservation equation which balances the opposite effects of turbulent resuspension and settling.

The net bottom resuspension mass flux was estimated using numerical simulations, and based on data rpublished by Kemp and Wells (1987) on the response of SSC to weather fronts in the study area (but in shallower depths). A key parameter controling settling is the settling velocity which was modeled following Wolanski (1989) and Hwang (1989). Initial values for SSC were interpolated from measured values of 1.0, 0.5, and 0.5 kg/m^3 at 1, 2 and 3 mab, respectively. With these values, the vertical distribution of the sediment concentration evolves in approximately 10 hours as shown in Figure 1. The final ``measured" value at 1 mab is the saturation value, given only as reference, as the actual measurement is rather an interval (SSC>1.7 kg/m^3), since the saturation level of the OBS is around 1.7 1.7 kg/m^3. The models forms a lutocline at the top of a layer with concentrations higher than 10 kg/m^3 and thickness about 1 m.

To approximate conditions on the Louisiana shelf, we performed some simulations of short wave propagation over a flat bottom of 5 *m* with a wide TMA spectum with a peak period of 7 seconds. The mud was assumed to be 100 times as viscous as water and 1.5 times as dense. A comparison of spectral energy density between the no-mud and with-mud cases is shown in Figure 2. The low frequencies are strongly dampened by the muddy bottom in comparison to the no-mud case, while the high frequencies are left fairly intact. This is an indication that the mechanism by Ng (2000) may not be sufficient for simulating processes seen on the Louisiana shelf.

IMPACT/APPLICATIONS

Much of the present and near-future Navy capability on predicting regional and nearshore processes assumes a sandy-non-cohesive sedimentary environment. The present research enhances this capability by identifying processes and developing mechanisms which allow expansion into areas which deviate from this.

RELATED PROJECTS

The project is closely aligned with the large multi-year NRL ARI entitled "Coastal Dynamics of Heterogeneous Sedimentary Environments" (PI. Dr. K. Todd Holland). Details can be found at: http://www7440.nrlssc.navy.mil/littoral%20dynamics/CDHeteroEnviro.html.

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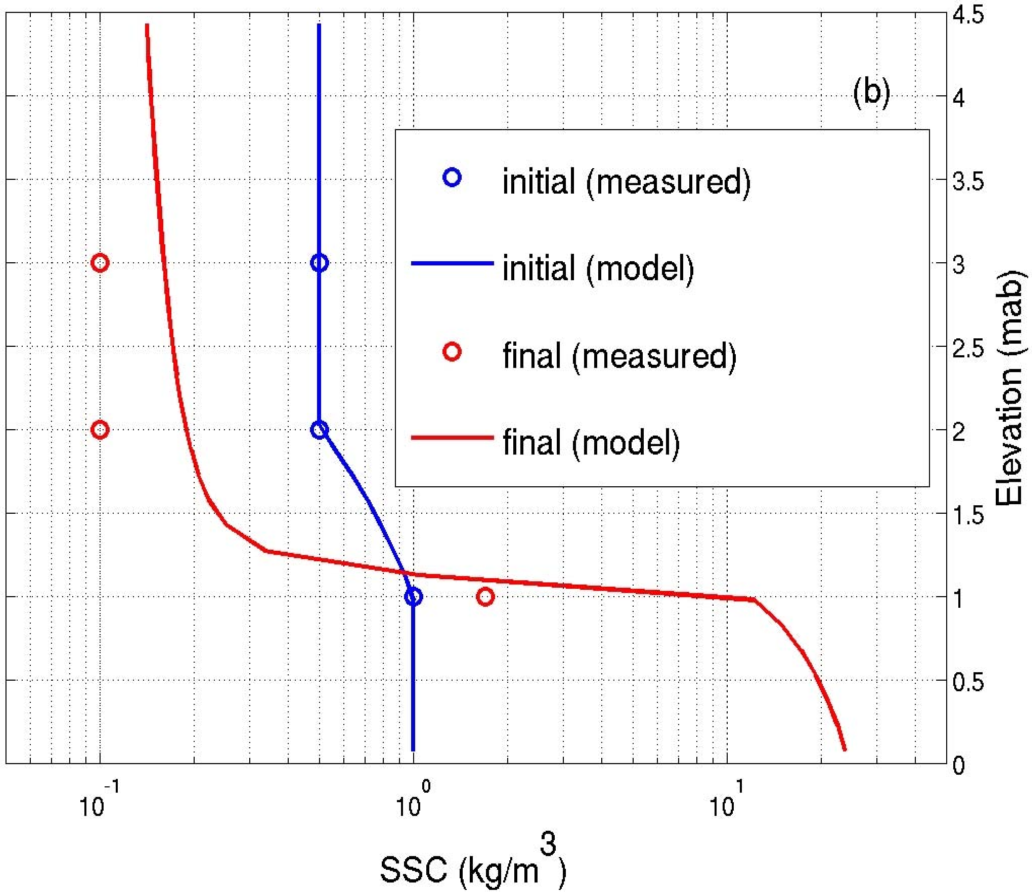

Figure 1: Vertical distribution of sediment concentration during the waning stage of Hurricane Claudette. Sediment (mud) dynamics are dominated by settling, as wave turbulence (and associated resuspension) begins to decay . Initial measured SSC (blue circles) correspond to concentrations at the beginning of the settling period. Final SSC values are 0.1 kg/m^3 for sensors at 2 and 3 mab. The SSC value for the 1-mab sensor (1.7 kg/m^3, the saturation value) is given only for reference.

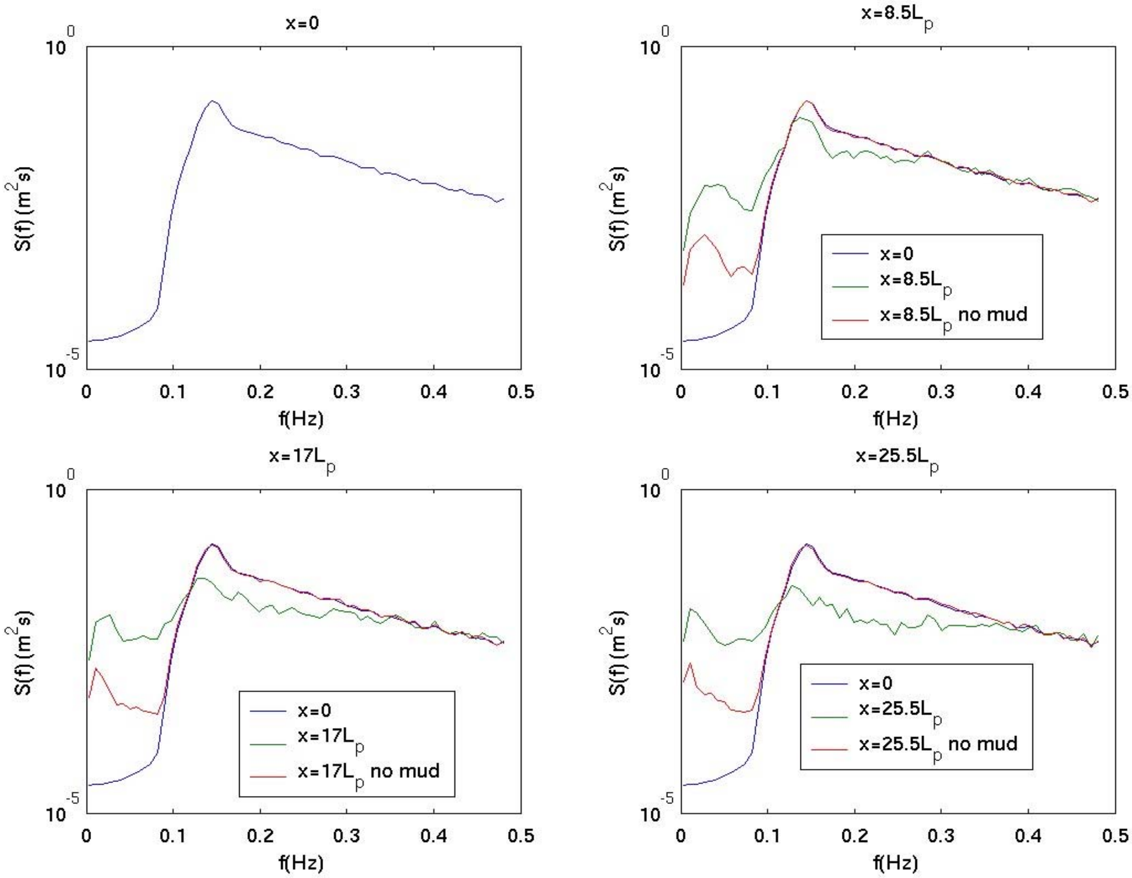

Figure 2. Nonlinear wave transformation over a flat bottom; with and without mud. Blue line: initial condition. Green line: waves over mud. Red line: No mud. Top left: initial condition. Top right: Spectra at 8.5 times peak wavelength. Bottom left: Spectra at 17 times peak wavelength. Bottom right: Spectra at 25.5 times peak wavelength. The effect of mud on the low frequencies is evident.